

IEEE Nuclear and Space Radiation Effects Conference: Notes on the Early Conferences

Jonathan A. Pellish, *Member, IEEE*, and Kenneth F. Galloway, *Fellow, IEEE*

Abstract— This paper gathers the remembrances of several key contributors who participated in the earliest Institute of Electrical and Electronics Engineers (IEEE) Nuclear and Space Radiation Effects Conferences (NSREC).

Index Terms— radiation effects and radiation hardness assurance

I. INTRODUCTION

THE Institute of Electrical and Electronics Engineers (IEEE) Nuclear and Space Radiation Effects Conference (NSREC) has a great heritage and, in July 2013, it will celebrate its fiftieth anniversary as a separate, distinct conference. The concept of this paper is to reach out to several of the individuals who attended one or more of the first three NSRECs and ask them for memories of those early conferences and entry into the field of radiation effects. In this paper, we will hear from a few well-known members of the radiation effects community telling us about those early conferences.

II. INDIVIDUAL REMEMBRANCES

We received excellent comments on the section of individual remembrances during the review process. There were many potential contributors to this section. In addition to the individuals cited explicitly, we acknowledge the importance of the many scientists and engineers that that made the early conferences so popular, productive and valuable. Some of the early NSREC influential engineers and scientists include Clay Rogers, Bob Caldwell, Bobby Buchanan, Harold Flescher, Orlie Curtis, and Ed Burke. We have done our best to capture a meaningful and representative sample of remembrances from the early days, but realize that providing a complete picture is nearly impossible.

Manuscript received June 20, 2012; revised manuscript submitted May 6, 2013. This work was supported in part by the NASA Electronic Parts and Packaging program and the Defense Threat Reduction Agency.

J. A. Pellish is with the NASA Goddard Space Flight Center, Flight Data Systems and Radiation Effects Branch, 8800 Greenbelt RD, Mail Stop 561.4, Greenbelt, MD 20771. Phone: 301-286-8046 Email: jonathan.pellish@nasa.gov.

K. F. Galloway is with the Department of Electrical Engineering and Computer Science, Vanderbilt University, Nashville, TN 37235. Email: ken.galloway@vanderbilt.edu.

Ours is a small, dynamic community with an enormous age range, making the present effort to preserve our collective history and experiences all the more important. This point was highlighted by the sad news that during the preparation of this manuscript two members of our community passed away: James Raymond (d. 08/24/2012) and Clay Rogers (d. 11/06/2012). Their passing is a huge loss to the community and we are proud to remember their accomplishments through this work.

The following set of remembrances highlights both the early Nuclear and Space Radiation Effects Conferences and some of the early work going on at that time. For more technical information on radiation effects prior to and during the 1960s we refer curious readers to papers by van Lint and Conrad [1, 2]. First person inputs are included in double-quotations. Square brackets are used where the authors included additional information or edited the text, except in the case of cited references, which also use the square brackets.

A. Edward Conrad



Figure 1: Edward Conrad.

At the time of the 1964 conference, Edward E. Conrad worked for the U.S. Army Harry Diamond Laboratories. At this meeting, he was elected as Chair of the IEEE Radiation Effects Committee. Ed was in attendance at the first three IEEE Nuclear and Space Radiation Effects Conferences and attended many more. His early nuclear weapons effects work at Harry Diamond Labs involved transient radiation effects on electronics research both in the laboratory and at the nuclear test sites. There was particular emphasis on radiation induced conductivity in dielectric materials as well as photocurrents and gain degradation in semiconductor devices. Over the years, he held a number of leadership positions associated

with the conference. Ed joined the Defense Nuclear Agency (DNA) in 1976 and was named Deputy Director of Science and Technology in 1979. As the scientific director at DNA, he was involved in research and development as well as the testing aspects of nuclear survivability across the Department of Defense. Upon retiring from the U.S. Government in 1983, he joined the Kaman Sciences Corporation where he retired in 1993. He now works as a private consultant.

Ed was the first Guest Editor of the IEEE Transactions on Nuclear Science to insist on peer review for the submitted NSREC conference papers. According to Ed, at first there was criticism from the managing editor, Dick Shea, because he considered it to be a form of elitism. However, Dick acquiesced and this practice became a major contributor to the high quality of NSREC papers. In 1994, Ed authored an IEEE Transactions on Nuclear Science paper that reviewed radiation effects research in the 1960s [2].

1) *Ed's Remembrances*

"All the three conferences were exciting because of the highly active research and development being conducted to understand nuclear threats and how to harden strategic and theater electronic weapon systems and to protect satellite systems from the natural and nuclear radiation environments. Coming to NSREC was always an emotional experience for me, both from a technological as well as a social point of view. I acquired life-long friends that were previously only names in paper references. Working in this field has always been a joy, even after I left the laboratory and became a people and money manipulator. I have been mentored, admonished and educated by many of my NSREC friends, and watching my own senior and junior laboratory colleagues rise to levels of technical competence far beyond my own capabilities has been a major source of satisfaction to me. When I look at the diversity of people who attend and contribute to this conference I am reminded of how much the world has shrunk, and truly become "flat." My first in-depth exposure to radiation damage research being conducted at universities and other organizations in Europe was in 1960 at a three-week radiation damage course at the nuclear research center near Ispra, Italy. The people I met there were highly competent, but Europe was slowly recovering from the devastation of World War II and travel money was very short. One saw only a very few European scientists and engineers at the early NSREC conferences. Now it is pleasing to see that so many of the major contributors to NSREC are our European and Asian members and associates.

Though the first conference to be called NSREC was held in 1964 at the University of Washington in Seattle, it can be misleading to view it as the birth of the "Early Days" without some reference to the political and technological climate that precipitated them. When NSREC was in its incubation, the United States (US) and its allies were in a very stressful stand-off with the Union of Soviet Socialist Republics (USSR) in what was called the Cold War. The Cuban Missile Crisis in 1962 has been described as the closest we came to the Mutually Assured Destruction disaster. Both adversaries pursued vigorous atmospheric nuclear testing programs. The

high altitude test, Starfish Prime, conducted by the US on 9 July 1962 over Johnston Island raised more questions than the answers it provided. The Electromagnetic Pulse (EMP) generated by that detonation caused power outages on the island of Oahu, Hawaii. At least nine orbiting satellites were damaged (seven were destroyed) by the enhanced radiation environment created in the magnetosphere. Examining the failure of the TELSTAR satellite kept Walter Brown of Bell Telephone Laboratories busy for a long time.

In addition to the Mutually Assured Destruction offensive and defensive assets that each major adversary had to investigate, there was an accompanying competition for world prestige between them in space exploration. The US launch of what was to be the first artificial Earth satellite was preempted by the launch of the USSR's SPUTNIK I on 4 October 1957, making the USSR the first space power. This initiated vigorous efforts within the US to "catch up." Ultimately, the US EXPLORER 1 and EXPLORER 3 satellites, in addition to collecting important geophysical data, confirmed the existence of the Van Allen radiation belts, a serious source of radiation damage to satellites. In spite of these stressful times, the formation of the National Aeronautics and Space Administration (NASA) and the US commitment to a vigorous space program continued and was further energized when President Kennedy made his "Going to the Moon" announcement in May 1961. Subsequently and continuously, NSREC included papers on the natural and nuclear-induced space environment effects (e.g., total ionizing dose and single-event upsets) that remain a threat to space-based electronic systems. [Both natural and nuclear-induced space radiation environment effects presentations were included in NSREC until the early 1980s. At that time, the community formed the Hardened Electronics and Radiation Technology (HEART) Conference, which has a restricted attendance policy.]

It is a near impossibility to cite the many landmark talks and papers that were given in "The Early Years." Some findings remain as foundations of our technology (e.g., modeling primary and secondary photocurrents, short-term annealing of neutron displacement damage, [and] charge trapping effects in metal oxide semiconductor systems), while other effects continue to frustrate us (e.g., neutron-induced displacement damage and single-event effects). Single-event upsets were recognized as a problem in "The Early Years," but continue to grow as a challenge while "Moore's Law" prevails.

Some of my fond memories include:

- My friend, Clay Rogers, grading papers submitted for a NSREC at varying degrees of "unacceptable;"
- The tipping over of an outhouse containing Clay Rogers at an NSREC social event;
- Jerry Hood renting mobile homes to bring the many members of his family to NSREC;
- Jim Crawford's 1968 paper on defects in semiconductors, in which he classified them as critters and varmints;
- Jim Raymond calling attendees back from a break with a clapper-less bell;

- Joe Srour's magic tricks; and,
- Ralph Stahl's paper summary template.

Over the years, NSREC has provided a wonderful forum for exchange of information that is sorely required for survivability in very stressing radiation environments. It was also a source of wonderful lifelong friendships and very fond memories of individuals who no longer exist."

B. William Price



Figure 2: William Price

William E. Price enjoyed a long and active career in radiation effects: Naval Research Laboratories (1953-1956), Pratt & Whitney (1956-58), Lockheed Research Laboratories (1958-1963), NASA Goddard Space Flight Center (1963-1966), Philco-Ford Aerospace (1966-1968), Autonetics/North America (1968-1969), and the California Institute of Technology Jet Propulsion Lab (JPL) (1970-1989).

He attended the first three NSRECs (1964, 1965, 1966) and only missed two until 1989. During this time, he held a number of conference and Nuclear and Plasma Sciences Society (NPSS) leadership positions.

His early work included studies of the effects of radiation on spacecraft materials, components, and electronic systems. Over his career he led work on most aspects of radiation testing and analysis, including the first heavy ion testing for single-event upsets.

Bill developed and wrote the first version of Test Method 1019 used in total ionizing dose testing of materials and electronic parts for which he was cited in receiving the IEEE Nuclear and Plasma Sciences Society Radiation Effects Award for "Significant Contributions to the Founding of the IEEE Nuclear and Space Radiation Effects Conference and drafting of the original MIL-STD-883, Test Method 1019" in July 1993.

1) Bill's Remembrances

"The true origins of NSREC go back much further than 1964. My involvement began in about 1955-56 while I was at the Naval Research Laboratory. I worked for Emanuel Brancato doing radiation testing of insulation materials. Brancato was a member of the AIEE Committee on Electrical Insulation. He started the "Radiation Effects to Insulation Subcommittee." I became Chairman of that subcommittee a few years later.

Within the Institute of Radio Engineers (IRE), about 1960, the Chairman of the Nucleonics Committee was Dr. J. C. Pigg of the Oak Ridge National Laboratory. Under this committee was a subcommittee known as Radiation Effects chaired by Dr. John Winslow. The two radiation effects subcommittees began holding joint meetings for a year or two because our fields of interest were complementary. A meeting would consist of five to eight people sitting around a conference table asking each other who knew someone who could give a technical paper on radiation effects at a conference. We usually got about five papers that way and composed a session at an AIEE meeting.

In 1962, Dr. John Winslow and I sent out the first Call for Papers, a one page flyer, to every lab or Company doing radiation effects work of which we were aware. We got 28 offerings and accepted 25. Winslow and I did all the functions including getting the paper summaries reviewed, organizing sessions, and getting session chairmen. The papers were arranged into a set of five sessions at the AIEE meeting in Denver that year. Interestingly, Dr. J. C. Pigg was a session chairman and introduced one of the authors in his session as "his country cousin – Dr. Calvin Hogg."

The next year, I believe, the meeting was held in Toronto and possibly [held jointly] with the IRE because I remember all of the key parties being present to merge the AIEE and the IRE. At this meeting, the formation of the Radiation Effects Technical Committee was carried out. I officially joined my Committee to Winslow's Committee with a vote by the membership present. We had a long discussion as to whether we would be a separate "Group." But Warren Witzig, Chairman of the IRE Nucleonics Committee, convinced us to be a Technical Committee under the "Nuclear Science Group." The word "Plasma" came some years later as did the designation of "Society." Now it's the Nuclear and Plasma Sciences Society. The original title for our committee was "Nuclear Radiation Effects Committee." I requested the addition of "Space" to the title because I worked in the space field for Lockheed at the time.

Dr. John Winslow from the Naval Radiological Defense Laboratory in San Francisco was [Chairman of NSREC for the first three years]. I was slated to follow him, but my employer at the time didn't want me spending company time on volunteer work (short sighted). So Dr. Edward Conrad was selected to be the second Chairman – a very good choice.

My memory is poor on who many of the early people were. I do remember Bill Snyder and Floyd Coppage of Sandia, Frank Poblentz of Bendix (later Texas Instruments), Bill Bohan of IBM, Carl Rosenberg and Bob Caldwell from the Boeing in Seattle, Dr. Victor van Lint of General Atomics Radiation Lab, and lots of others. I remember van Lint being author of a lot of papers in the early conferences.

The Administrative Committee of the Nuclear Science Group in those days felt that our Committee reviewed papers too thoroughly – we reviewed the abstracts and then, again, the final papers resulting in delays to publication. But I believe that that procedure led to our Committee turning out the fine work for which we are noted.

I worked for the Goddard Space Flight Center from 1963 to 1965, which allowed me to be more engaged in IEEE work. So, I was selected to be on the Administrative Committee of the Nuclear Science Group (later the Nuclear and Plasma Sciences Society) for three years where I was Secretary/Treasurer for two years. I served in various capacities in the Radiation Effects Committee through the early years. I was the original author of Method 1019 through the first two or three revisions, and it is still a bulwark for total dose testing of materials and electronic devices today.

My work at JPL was the culmination of a career in Radiation Effects. It brought all my experience and background into play to harden the Voyager spacecraft (and other spacecraft afterwards) against the high radiation fields at Jupiter – and we were successful because it carried out its mission by passing by four planets and getting the data and pictures required. [It has now ventured into interstellar space.] Great stuff!!

I learned a great deal at NSREC meetings and made a number of useful contacts. I even arranged joint testing with other groups several times while at the conferences. Best of all, I made lasting friendships with engineers and scientists all over the world. I have hosted a number of small groups in my home. I still miss the camaraderie we all had at the many Conferences.”

C. Victor A.J. van Lint



Figure 3: Victor van Lint

Dr. Victor A.J. van Lint developed the program on radiation effects in electronic materials, devices, and systems at General Atomic (1957-1973). This General Atomic unit was sold to Intelcom Industries and van Lint was president of Intelcom Rad Tech (1973-1974). He served as a private consultant (1974-1975) when he formed the San Diego Division of Mission Research Corporation (MRC). He took a leave of absence (1982-1983) to work at the Defense Nuclear Agency (DNA). He left MRC in 1991 to form a one-person company, VvL, Inc. He survives his wife, June van Lint, who passed away peacefully on 03/30/2013.

His initial interests were in the mechanisms of ionization and displacement radiation effects in electronic materials, especially semiconductors and insulators, with special emphasis on the effects of multi-MeV electron exposures. These interests soon extended to devices, circuits, and

systems. By 1964, he was heavily involved in pulsed ionization testing of microcircuits for the Minuteman II and in radiation effects analysis and testing for the Avco MK-11A SleighRide program. Over the years, he provided support to numerous agencies and systems. In 1994, Vic authored an IEEE Transactions on Nuclear Science paper that reviewed radiation effects research before 1960 [1].

1) Vic's Remembrances

“Leading up to the formal NSREC, I attended the radiation effects session at the AIEE summer general meeting in Denver in 1962 and presented a summary paper on transient radiation effects. I was then asked to present an invited paper on the “Mechanisms of Transient Radiation Effects” at the Nuclear Radiation Effects Conference during the IEEE Summer General Meeting in Toronto in 1963 [3]. I did not attend the 1964 meeting at University of Washington in Seattle. I remember attending the 1965 meeting at University of Michigan in Ann Arbor. I was the Papers Chairman of the 1966 meeting at Stanford University, where Don Nichols and I presented a paper on “Theory of Transient Electrical Effects in Irradiated Insulators” [4]. I’ve always thought this was one of my more important contributions and was surprised that it became controversial.

I remember the 1966 Conference at Stanford University well, because the papers committee had to work hard before the conference to pare the paper selection to fit the schedule, and an auto accident soon after the conference left my wife as a quadriplegic. I attended most of sessions and concluded that the decision not to have parallel sessions had been appropriate. Most of the accepted papers were eventually reviewed and published in the [IEEE] Transactions on Nuclear Science. The local arrangements were excellent. I remember that my wife thoroughly enjoyed excursions with other spouses. Bill Price reminds me that his kids provided child care for our four, who were between two and ten years old at the time.”

D. Floyd N. Coppage



Figure 4: Floyd Coppage

Floyd Coppage attended the first three NSRECs. During this time he worked for Sandia National Laboratories (SNL). He retired from SNL in 1986 and then worked for RDA/Logicon until a second retirement 1993. At the time of the early conferences, Floyd was contributing to the B-61 and MK-3 submarine-launched ballistic missile programs and his

efforts were primarily aimed at the effects of radiation on dielectrics (organics), including both permanent damage and transient effects. He also examined damage to diodes and transistors.

1) *Floyd's Remembrances*

"With the realization that nuclear radiation affected the entire system came this "new science" called radiation effects, aimed at identifying and understanding the complex interactions of the radiation with the materials and devices that made up the system. This was a new and exciting era in physics and engineering. As the understanding of the effects of radiation matured, then came the challenge of determining what could be done to harden devices and materials to make the system tolerant of this new environment. This was an exciting time of back to the basics, trial and error testing, and some of 'let's just see what happens.'"

E. *George C. Messenger*



Figure 5: George Messenger

George C. Messenger has a long history of involvement with the IEEE NSREC. He attended all three early conferences. At the early conferences, he was a consultant to Boeing, but actually employed by Philco-Ford Aerospace. At the time, his research was on nuclear effects in diodes and transistors. As a consultant to Rockwell, he managed a program to harden the airborne electronics for the Minuteman missiles and he managed a number of tests of the Minuteman electronics at the Nevada Test Site and at other facilities for testing radiation effects. His research provided a model for the effect of displacement on bipolar transistors and other effects due to bursts of ionizing radiation in bipolar transistors. He also made contributions to electromagnetic pulse (EMP) hardening of the Minuteman missile. In addition to his attendance at the early conferences, George was a speaker at the first NSREC Short Course in 1980 and was Local Arrangements Chair for Las Vegas, NV NSREC in 1982.

1) *George's Remembrances*

"Radiation damage data, especially for neutrons, was unreliable. Some data were reported as sulfur neutrons. The 1 MeV equivalent was not established. EMP was not established as a viable damage mechanism. Government control of research was not effectively established and centralized. Peter Haas at the Defense Atomic Support Agency, [one of the predecessor elements of the Defense

Threat Reduction Agency,] was the first effective manager. I was unable to secure any government contracts. I did all my research under consulting contracts with various original equipment manufacturers. This made it extremely difficult for me to do effective research, although I did succeed.

As a consultant to Rockwell, I was made manager of the program to harden the airborne electronics for the Minuteman missiles, and managed a number of tests of the Minuteman electronics at the Nevada Test Site and at other facilities for testing radiation effects. Our research resulted directly in the discovery of the Messenger-Spratt equation for the effect of radiation induced displacement damage effects on bipolar transistors and microcircuits [5]. My research also resulted directly in the discovery of the Kirk effect explaining the transient reduction in frequency response of bipolar transistors and microcircuits due to very short, very large pulses of high energy ionizing radiation. I also contributed to research for hardening the Minuteman missile against the effects of EMP pulses. I was issued US patent #3,492,547 for radiation hardened semiconductor devices. This is the basic patent for semiconductor devices hardened for military applications."

2) *Some Remembrances of George Messenger from Ed Conrad's Invited Talk at the 2010 NSREC*

"The ubiquitous George Messenger was at every NSREC I ever attended, including all of the early conferences. In fact, I remember him giving talks long before NSREC began. George is a super engineer. I can't remember if he was working at Rockwell, Philco, Hughes or Northrop, but regardless, George was always there. The number of organizations he has worked for might lead one to believe that he can't hold a job, but I'm sure his migrations have been the result of his entrepreneurial motivation and technical skills. His 1958 paper, with Jim Spratt, is a landmark paper that provided a means of organizing neutron-induced macroscopic reduction in bipolar transistor gain and relating it to neutron displacement effects on carrier lifetime. Whenever a new semiconductor radiation effects problem arose, George would dive into it at great depth and sophistication, solve it, and apply it to the manufacturing line. His talks were always well prepared and authoritative. George is truly an 'engineer's engineer.'"

F. *James P. Raymond*

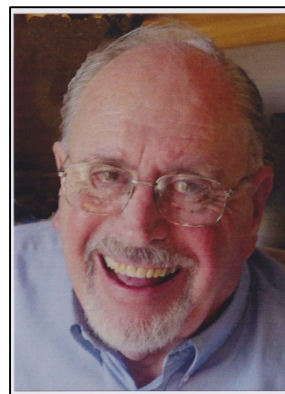


Figure 6: James Raymond

Jim Raymond missed the first conference. However, starting in 1965, he attended every NSREC for more than 35 years. He served as Session Chairman, Short Course Presenter, Short Course Chairman, Guest Editor, Awards Chairman, Treasurer, and Conference General Chairman (1979). Jim worked for Northrop, served as a consultant, and then retired from Mission Research Corporation.

1) *Jim's Remembrances*

"My first experience with the NSREC was pouring over the articles published in the Proceedings of the 1963 Toronto conference, particularly the ground-breaking articles on diode and bipolar transistor photoresponse published by the Boeing group. By the following year, I submitted an abstract to the 1964 NSREC in Seattle, WA. The paper was accepted, but Northrop management decided that they could not afford to send me to the conference. As a result, the paper was read for me in Seattle, WA by George Messenger. When it became time to submit a manuscript [to the Transactions on Nuclear Science], I decided that the quality of the paper was not sufficient for publication. I discovered my error when I received my copy of the Transactions. I never made the same mistake again.

I presented my first NSREC paper at the 1965 conference at the University of Michigan on diode and bipolar transistor modeling. Our approach was somewhat controversial, and it was my first experience in the intensity and competitive spirit of the conference at the time. I also submitted a modeling paper to the 1966 conference, and was introduced to Frank Poblentz who was the conference guest editor. We got along well, and, in a moment of great weakness, I found myself with the duty of the 1967 guest editor. In those days, the duties were well defined – I was the entire staff. I did, however, have the pleasure of meeting Dick Shea who was the long-time editor of the Transactions on Nuclear Science.

Through my experiences and duties of the early years of the NSREC, there was an intense experience of competition, but also a strong experience of community bonding. The conjunction lead to some very intense discussions both after the presentation of a paper with the audience, with the conference experiments of round-table discussions, and with the frolicking during the obligatory conference social.

Now, well into my retirement, I must admit that I don't miss the work, long hours, and pressure, but I do miss my membership as a member of the community – it was a pleasure and honor for me."

G. Harold L. Hughes



Figure 7: Harold (Hap) Hughes

Hap wanted to present at the 1964 conference, but his groundbreaking paper on metal oxide semiconductor (MOS) total ionizing dose (TID) radiation effects was rejected and he was unable to attend. He attended the 1965 and 1966 conferences and many more, serving later as session chairman, guest editor in 1970, and general chairman in 1977. Hap presently works for the Naval Research Laboratory (NRL), as he has since 1960, and continues to be an active NSREC participant.

1) *Hap's Remembrances*

"The aforementioned paper submitted to the 1964 NSREC was rejected because radiation effects were not expected in MOS majority carrier technology. In today's world this effects paper may have been accepted for the NSREC Radiation Effects Data Workshop, which, however, did not exist in 1964. Until that time, TID radiation effects in semiconductor bipolar devices were based on minority-carrier effects, and MOS devices, being majority-carrier in nature, were expected to be inherently rad-hard. So when the journal Electronics contacted NRL a few months later for some data to fit into their upcoming special December MOS issue, data were extracted (limited to 3 pages) from the paper previously submitted to 1964 NSREC. The Electronics paper then became the first, but abridged, paper to show MOS radiation effects. The following year's paper, accepted by NSREC, NRL introduced not just new data, but a new radiation effects model [6]. The established model for surface effects of radiation was being challenged by NRL. Until that time, it was held that radiation induced ionization of the package gas ambient caused the observed surface effects in devices [7]. NRL disproved the gas ionization model for devices with oxide regions by performing irradiations in ultra-high vacuum, with no gas present around the device, and yet still observed the same surface effects. Device current-voltage data, coupled with capacitance-voltage characterizations, were used to show that radiation induced charges were incorporated within the oxide and, thus, not due to radiation induced ions on the surface [6]. The newly-found damage effect of radiation-induced charge buildup in gate oxides of MOS transistors was confirmed by other groups and with other radiation sources,

including: a flash x-ray generator, a TRIGA reactor, and high energy electrons.”

H. Andrew Holmes-Siedle

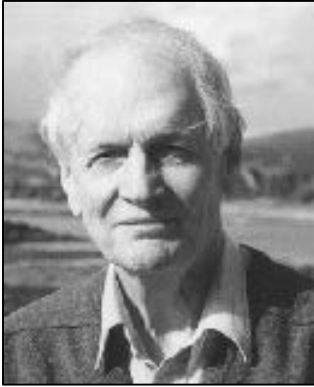


Figure 8: Andrew Holmes-Siedle

Dr. Andrew Holmes-Siedle worked for the Radio Corporation of America (RCA) Astro-Electronics Division in Princeton, NJ at the time of the first NSREC and participated in the first three NSRECs. He was a panel speaker in 1965 and gave papers on complementary metal oxide semiconductor (CMOS) ionization effects in 1965 and CMOS transient effects in 1966. Andy’s early work emphasized space and military hardening of CMOS devices and he contributed to hardening of the NASA TIROS weather satellite and Navy NAVSAT satellite. On return to the United Kingdom (UK), he formed his own firm in 1975, REM Oxford Ltd., where he is still active.

It is worth noting that the reason Andy came to work at RCA in 1962 had to do with a brewing competition between RCA and Bell Telephone Laboratories (BTL) over solar cell design for spacecraft. This was borne out immediately with the launch of the RELAY satellite, which actually flew and demonstrated both types of solar cells. For additional information on the TELSTAR and RELAY satellites, the reader may want to review two *Bell Systems Technical Journal* articles [8, 9].

Andy received the IEEE Nuclear and Plasma Sciences Society Radiation Effects Award in 2001 with the citation “For contributions to the field of radiation dosimetry and his encouragement of young researchers in the field of radiation effects.”

1) Andy’s Remembrances

“The IEEE and NSREC came into my life with a jolt. I had been hired from the UK by RCA to handle radiation effects in silicon [initially on RCA solar cells]. Instead, I found myself coping with an engineering emergency. The first nuclear explosion in outer space (STARFISH Prime, July 1962) had raised the space environment and damaged or destroyed several orbiting satellites, including the ARIEL 1, which was the first international-collaboration satellite project. The 1962 scene is well set in a 2012 article entitled “How the U.S. Accidentally Nuked Its Own Communications Satellite” [10].

The requirement was to harden, within weeks, a RCA satellite near-ready for launch. We did the job, launched the

satellite (RELAY) and it worked well. The consequences included a promotion, a NASA contract on metal oxide semiconductor field effect transistors (MOSFETs), and a place on a NSREC 1965 panel on space, chaired by Fred Gordon of NASA. My nascent research and development group tested a lot of silicon including MOSFETs, soon to become complementary metal oxide semiconductor integrated circuits (CMOS ICs). What is more, RCA corporately had set its sights on making “hard CMOS.” As a result, from 1965 to 1971, we gave papers to the Transactions on Nuclear Science or NSREC, on average one or two a year. Bill Snyder asked me onto the committee as chairman of publications. I concur with Jim Raymond (this article) – there was no confusion at that time about who did what – you were the chairman of one person – yourself. The conference was a blur of chasing authors and you went home with a sack full of hard copies to edit.

Two of my researchers, Bill Dennehy and George Brucker, were regular presenters at NSREC. For me, Toronto 1963 was the eye-opener; Stanford 1966 was RCA’s opening shot on radiation effects in CMOS and we finished our research trajectory with a paper at Durham, NH in 1971, on a self-designed [rad]-hard silicon-on-sapphire pMOS integrated circuit, including pulsed data from the Air Force Cambridge Research Laboratories’ linear accelerator. That was perhaps our best work, but it was not widely noticed.

When I went back to Europe to ply the same trade, NSREC continued to be a great network, source of information, and, as it still is, a friendly multinational club. Life in the radiation community is rarely dull and will be enlivened by a RADECS conference in Oxford UK, September 2013, with IEEE participation, of course.”

I. Allan H. Johnston



Figure 9: Allan Johnston

Allan Johnston is still an active contributor to the conference. He first attended the NSREC in 1966 while employed at Boeing Aerospace, and has attended the majority of the conferences since that time. His earlier work was on transient and permanent damage effects on microelectronics, which were first starting to be used in military and space systems in the late 1960’s. He was a speaker at the first NSREC Short Course (1980), and subsequently held many different conference positions, including General Chairman of

the IEEE NSREC in 2003. He joined the Jet Propulsion Laboratory in 1992, and continues to work on space radiation effects in microelectronic and optoelectronic devices.

1) *Allan's Remembrances*

"The first conference I attended was 1966 [Stanford]. I was new to the field, and felt somewhat intimidated and out of place. Although a few people at that meeting were aware of the earlier activities, there wasn't any sense of legacy or continuity; it was simply a technical conference. I don't believe that anyone at that time would have expected the conference to continue for 50 years. However, the early organizers stressed technical quality, and started the thorough peer review process that we have today before papers were accepted at the conference. Even after the initial reviews for the conference, a lot of papers didn't make it to final publication.

A wide variety of topics was covered in the meeting, and only a few people had the experience and depth of understanding that was needed to understand all the papers (in my opinion that is still true today). The conference had a very different feel. All the men were in coats and ties, and the few women in attendance wore conservative dresses with heels. Twenty minutes were allocated for each paper, and the question and answer period was much more interesting than today, often evolving into emotional shouting matches. The speaker had the advantage, because he alone had a microphone. However, some of the strong personalities in the audience were very effective in shouting their questions. There was a lot of back and forth, particularly between Bill Bowman (Boeing), Jim Raymond (Northrop), and George Messenger (also Northrop). Without the delay of handing a microphone around, there was a lot more spontaneity.

Other personalities include Clay Rogers, who had a wry, commanding insight into many of the issues; and Orlie Curtis (Northrop), who later left the field to go into law. Orlie was an extremely able speaker, with a deep knowledge of fundamental mechanisms. Everyone listened carefully when he spoke up.

We had invited speakers at that time, just like today. At the Stanford Conference, Prof. R. H. Bube gave one invited talk on CdSe; he was the author of a well-known book, *Photoconductivity of Solids*. The 1966 conference had three round-table discussions that were quite interesting because they provide better insight compared to technical papers, and also allowed "unsettled" issues to be brought up.

Social functions were much simpler. There were coffee breaks, but only one actual planned function (a banquet in 1966). Most evenings were "open." The strong personalities from the aerospace companies usually got together for dinner and drinks, continuing and extending their discussions.

If we look back at the conference, most of the papers were given by aerospace companies, not universities and government labs. Northrop was a particularly strong organization, but several other companies were also key technical contributors. The one exception to the previous rule was Sandia National Laboratories, which did some excellent work and was a strong organization. The Outstanding Paper

Award was given to Howard Sander and (a very young) Bob Gregory, for their work on transient annealing. At that time, most government labs contracted the majority of the technical work; our contracts at that time even included support to attend the conference. A technical paper was expected (and paid for) by the sponsors. [Those were] truly the "good old days."

That situation has changed dramatically, starting in the early 1980s. Today, universities and government laboratories present most of the papers, and will likely continue to do so. The format is also different. Nearly the entire week is tied up due to the addition of the Short Course (which added another day to the meeting), evening receptions, the poster session, and the data workshop, which more than doubles the number of papers.

Returning to the technical issues, in the late 1960s solid-state devices and integrated circuits were relatively new. A lot of people had been formally trained on vacuum tubes, but were struggling to understand the details of solid-state devices, which did not perform very well when exposed to radiation. There was only a limited amount of information available, and going to the literature required browsing the journals, or picking the brains of an experienced colleague. A lot of the papers at that time were motivated by defense. When I look back at the 1966 journal, 42 papers were published from the conference, and only about 10 are clearly oriented towards space. Most of those dealt with discrete transistors. In contrast, radiation effects in space is the dominant problem today. The main reason is the emergence of single-particle effects (starting in 1975), along with the tremendous increase in integration density and complexity."

J. Joe R. Srouer



Figure 10: Joe Srouer

The following notes are adapted from an earlier publication by Joe, published in 1994, which recounts radiation effects research and development efforts in 1970s [11], forming a bridge between those early conferences and the modern NSREC that we have now.

1) *Joe's Remembrances*

"Some personal reminiscences of IEEE Nuclear and Space Radiation Effects Conferences in the 1970s are given here. Starting with 1970 and continuing through 1980 in chronological order, those conferences were held in the

following cities: San Diego, CA; Durham, NH; Seattle, WA; Logan, UT; Fort Collins, CO; Arcata, CA, San Diego, CA, Williamsburg, VA; Albuquerque, NM; Santa Cruz, CA, and Ithaca, NY.

The 1970 San Diego conference featured notable technical papers and a very nice banquet at the Hotel del Coronado. I remember well the New England clambake held in Durham. At the Seattle conference in 1972, we enjoyed a boat trip to Kana Lodge followed by a salmon feast. The Logan conference in 1973 featured an excellent cook-out at a nearby park. Some attendees chilled their preferred beverages in a local stream at that function. Who can forget the western cook-out on a barren plot in Fort Collins in 1974? Many excellent papers were presented at the Arcata Conference; the interested reader is referred to the December 1975 issue of the IEEE Transactions on Nuclear Science. I also recall Polynesian dancers on a foggy mountaintop at that meeting. We returned to San Diego in 1976 and enjoyed diverse beach activities. In Williamsburg, attendees appreciated the fish house punch served at the Wren Building. They also found the climate balmy at the cook-out at Jamestown Festival Park. At Albuquerque in 1978, Howard Sander, the Local Arrangements Chairman, planned and conducted a memorable social event: the Fiesta Grande! The Call for Papers for the Albuquerque conference provided an example format for the extended summary that described a method for determining and maximizing the number of interstate faces (or out-of-state attendees) at radiation effects conferences.

Many of us recall the interesting 75-minute train ride through the forest at the Santa Cruz conference cook-out in 1979. Some train riders who enjoyed pre-ride beverages were painfully aware of the lack of onboard rest rooms; they were observed to leap off the train and run for land-based facilities just before the ride was completed. Frank Drake presented an excellent invited lecture on the search for extraterrestrial intelligence at the Cornell conference in 1980. At the completion of his talk, Otto the Robot joined him on stage. We also recall George Messenger being sawed in half during another invited talk at Cornell. For a pictorial account, see page 1386 of the December 1980 issue of the IEEE Transactions on Nuclear Science. I am happy to report that George has annealed well through the years since that magical splitting of the abdomen.

I cherish my memories of radiation effects conferences in the 1970s. We really did work hard and play hard."

III. APPENDIX

A. Photos of Early NSREC Participants

The photos in this section are taken from the invited presentation given by Ed Conrad at the 2010 NSREC in Denver, CO [12]. Any captions included with the photographs are also from the annotated version of that same presentation.



Figure 11: Principal NSREC founders, (from left-to-right) Emanuel Brancato, Bill Price, and John Winslow.



Figure 12: Samuel Clay Rodgers



Figure 13: Orlie Curtis



Figure 14: Bobby Buchanan

IV. REFERENCES

- [1] V. van Lint, "Radiation effects before 1960," *IEEE Trans. Nucl. Sci.*, vol. 41, no. 6, pp. 2642-2647, Dec. 1994.
- [2] E. E. Conrad, "Radiation effects research in the 60's," *IEEE Trans. Nucl. Sci.*, vol. 41, no. 6, pp. 2648-2659, Dec. 1994.
- [3] V. A. J. van Lint, "Mechanisms of Transient Radiation Effects," *IEEE Trans. Nucl. Sci.*, vol. 10, no. 5, pp. 11-19, Nov. 1963.
- [4] D. K. Nichols, and V. A. J. van Lint, "Theory of Transient Electrical Effects in Irradiated Insulators," *IEEE Trans. Nucl. Sci.*, vol. 13, no. 6, pp. 119-126, Dec. 1966.
- [5] G. C. Messenger, and J. P. Spratt, "The Effects of Neutron Irradiation on Germanium and Silicon," *Proc. IRE*, vol. 46, no. 6, pp. 1038-1044, Jun. 1958.
- [6] H. L. Hughes, "Surface Effects of Space Radiation on Silicon Devices," *IEEE Trans. Nucl. Sci.*, vol. 12, no. 6, pp. 53-63, Dec. 1965.
- [7] R. R. Blair, "Surface Effects of Radiation on Transistors," *IEEE Trans. Nucl. Sci.*, vol. 10, no. 5, pp. 35-44, Nov. 1963.
- [8] W. L. Brown, J. D. Gabbe, and W. Rosenzweig, "Results of the Telstar Radiation Experiments," *Bell Systems Tech. J.*, vol. 42, no. 4, pp. 1505-1560, Jul. 1963.
- [9] W. L. Brown, T. M. Buck, L. V. Medford, E. W. Thomas, H. K. Gummel, G. L. Miller, and F. M. Smits, "The Spacecraft Radiation Experiments," *Bell Systems Tech. J.*, vol. 42, no. 4, pp. 899-941, Jul. 1963.
- [10] S. R. Das, "How the U.S. Accidentally Nuked Its Own Communications Satellite," *Scientific American*, <http://www.scientificamerican.com/article.cfm?id=how-us-accidentally-nuked-own-communications-satellite>, [22 April 2013, 2012].
- [11] J. R. Srouf, "Radiation Effects R&D in the 1970s: A Retrospective View," *IEEE Trans. Nucl. Sci.*, vol. 41, no. 6, pp. 2660-2665, Dec. 1994.
- [12] E. E. Conrad, "Reflections on 47+ Years of NSREC," in *IEEE Nuclear and Space Radiation Effects Conf.*, Denver, CO, 2010.